

031

**PCT**WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : B01J 31/08, C08J 9/18, C08L 27/02	A1	(11) International Publication Number: WO 00/44495 (43) International Publication Date: 3 August 2000 (03.08.00)
(21) International Application Number: PCT/US00/02102 (22) International Filing Date: 28 January 2000 (28.01.00) (30) Priority Data: 60/117,699 29 January 1999 (29.01.99) US (71) Applicant: E.I. DU PONT DE NEMOURS AND COMPANY [US/US]; 1007 Market Street, Wilmington, DE 19898 (US). (72) Inventors: LLOYD, Ralph, Birchard; 6124 Lochview Drive, Fayetteville, NC 28311 (US). HOWARD, Edward, G.; 844 Old Public Road, Hockessin, DE 19707 (US). (74) Agent: HENDRICKSON, John, S.; E.I. Du Pont de Nemours and Company, Legal Patent Records Center, 1007 Market Street, Wilmington, DE 19898 (US).	(81) Designated States: CN, JP, RU, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the</i> <i>claims and to be republished in the event of the receipt of</i> <i>amendments.</i>	
(54) Title: POROUS HIGHLY FLUORINATED ACIDIC POLYMER CATALYST AND PROCESS FOR ITS PREPARATION (57) Abstract This invention relates to a solid acid catalyst comprising porous highly fluorinated acidic polymer and process for manufacturing it. The catalyst comprises at least 90 wt.% highly fluorinated acidic polymer and has a surface area of about 0.01 m ² /g to about 5 m ² /g. The catalyst is prepared by exposing the polymer to a pressurized fluid such as SO ₂ or CO ₂ , heating the polymer to above the softening point, reducing the pressure quickly thus expanding the polymer into a porous structure, and cooling the polymer. Examples of the highly fluorinated acidic polymer are perfluorinated sulfonic acid resin perfluorinated and sulfonyl fluoride polymer.		

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SE	Sweden
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Cote d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon		Republic of Korea	PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakhstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

TITLE

POROUS HIGHLY FLUORINATED ACIDIC POLYMER CATALYST AND PROCESS FOR ITS PREPARATION

FIELD OF THE INVENTION

The present invention relates to solid acid catalysts and more

- 5 particularly relates to a porous highly fluorinated acidic polymer catalyst and a process for its manufacture.

BACKGROUND OF THE INVENTION

- Perfluorinated sulfonic acid polymer is known for use as an acid catalyst in a variety of chemical reactions (F. J. Waller, et al. *Chemtech*, July 1982, pp. 438-
10 441). The polymer is used in a variety of physical forms, including powder, particles and pellets in a range of sizes and shapes, films, and tubes. High surface area is generally desirable to facilitate contact of the polymer with the material or materials with which it interacts, and to make most efficient use of the polymer. Surface area can be increased by more finely dividing the solid polymer, or by
15 using the polymer on or in a substrate as described in U.S. Patents 5,430,212 and 5,824,622. Finely divided polymer can pack and obstruct flow in continuous processes in which reactants pass through a catalyst bed. Carry-over of fines and resulting down-stream contamination is also a problem. Cleaning spent polymer is complicated by these same factors. By combining the polymer with a
20 substrate, high surface area may be achieved without finely dividing the polymer. However, the substrate can interact with the strongly acid polymer and affects its activity. Separation of polymer from the substrate, and attrition of the substrate during use are also problems.

- New forms of perfluorinated sulfonic acid catalyst are needed which
25 have high surface area but avoid the problems inherent in finely divided polymer or polymer-on-substrate forms of catalyst.

SUMMARY OF THE INVENTION

- In accordance with the invention, a solid acid catalyst is provided which comprises porous highly fluorinated acidic polymer. The catalyst is
30 comprised of at least about 90 wt.% highly fluorinated acidic polymer and has a surface area of about 0.01 m²/g to about 5 m²/g. Preferably, the catalyst is substantially free of pores having a size of about 1.7 to about 300 nm as measured

by the BET absorption method. Preferably, the highly fluorinated acidic polymer is highly fluorinated sulfonic acid polymer.

In accordance with a process for making a solid acid catalyst in accordance with the invention, highly fluorinated acidic polymer or precursor thereof is exposed to a pressurized fluid to produce fluid-swelled polymer or polymer precursor. The fluid-swelled polymer or polymer precursor is heated to a temperature above the softening point of said fluid-swelled polymer or precursor. The pressure of the pressurizing fluid is then reduced sufficiently quickly that gases escape from said fluid-swelled polymer and the escaping gases expand said polymer or polymer precursor into a porous structure. The polymer or polymer precursor is cooled to at least partially retain the porous structure.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1 and 2 are photomicrographs at 50X and 500X, respectively, of a preferred catalyst in accordance with the present invention prepared according to the procedure described in Example 1.

Figure 3 and 4 are photomicrographs at 50X and 500X, respectively, of a preferred catalyst in accordance with the present invention prepared according to the procedure described in Example 2.

DETAILED DESCRIPTION

The solid acid catalyst in accordance with the invention contains highly fluorinated acidic polymer. "Highly fluorinated" means that at least 90% of the total number of univalent atoms in the polymer are fluorine atoms. Most preferably, perfluorinated acidic polymers are used. The highly fluorinated acidic polymers useful for the present invention include polymers with acidic functional groups including sulfonic, carboxylic, phosphonic, imide, sulfonimide and sulfonamide groups. Preferably, polymers containing sulfonic acid groups are used because of their strongly acidic character and ready commercial availability.

Preferably, the solid acid catalyst contains at least about 90 wt.% and, more preferably 95 wt.%, highly fluorinated acidic polymer. In the most preferred form of the invention, the solid acid catalyst consists essentially of highly fluorinated acidic polymer.

In preferred polymers for use in accordance with the invention, the polymers comprise a polymer backbone with recurring side chains attached to the backbone with the side chains carrying the cation exchange groups. In use the polymers should be principally in the acid form, that is, the proton or hydrogen ion form, though some cation exchange groups may be in the salt form, that is, associated with cations other than the proton or hydrogen ion. Especially preferred are polymers in which the side chains are fluorinated as this enhances the acidity of the ion exchange group. Highly fluorinated and perfluorinated acidic polymers for use in accordance with the invention can be homopolymers or copolymers of two or more monomers. Copolymers are typically formed from one monomer that is a nonfunctional monomer and which provides carbon atoms for the polymer backbone. A second monomer provides both carbon atoms for the polymer backbone and also contributes the side chain carrying the cation exchange group or its precursor, e.g., a sulfonyl halide group such as sulfonyl fluoride ($-\text{SO}_2\text{F}$), which can be subsequently hydrolyzed and acid exchanged to a sulfonic acid group. For example, copolymers of a first fluorinated vinyl monomer together with a second fluorinated vinyl monomer having a sulfonyl fluoride group ($-\text{SO}_2\text{F}$) can be used. By fluorinated vinyl monomer is meant a molecule with a carbon-carbon double bond in which there is at least one fluorine atom attached to a carbon atom which is doubly bonded to another carbon atom. Possible first monomers include tetrafluoroethylene (TFE), hexafluoropropylene, vinyl fluoride, vinylidene fluoride, trifluoroethylene, chlorotrifluoroethylene, perfluoro(alkyl vinyl ether), and mixtures thereof. Possible second monomers include a variety of fluorinated vinyl ethers with sulfonate ion exchange groups or precursor groups which can provide the desired side chain in the polymer. The first monomer may also have a side chain which does not interfere with the ion exchange function of the sulfonate ion exchange group. Additional monomers can also be incorporated into these polymers if desired.

A class of especially preferred polymers for use in the present invention includes a highly fluorinated, most preferably perfluorinated, carbon backbone and the side chain is represented by the formula

$$-(\text{O}-\text{CF}_2\text{CFR})_n-\text{O}-\text{CF}_2\text{CFR}'\text{SO}_3\text{X}, \text{ wherein } \text{R}' \text{ and } \text{R}'' \text{ are independently}$$

selected from F, Cl or a perfluorinated alkyl group having 1 to 10 carbon atoms, a
= 0, 1 or 2, and X is entirely or largely H, but may include minor amounts of Li,
Na, K or N(R¹)(R²)(R³)(R⁴) and R¹, R², R³, and R⁴ are the same or different and
are H, CH₃ or C₂H₅. The preferred polymers include, for example, polymers
disclosed in U.S. Patent 3,282,875 and in U.S. Patents 4,358,545 and 4,940,525.
One preferred polymer comprises a perfluorocarbon backbone and a side chain
represented by the formula -O-CF₂CF(CF₃)-O-CF₂CF₂SO₃X, wherein X is as
defined above. Polymers of this type are disclosed in U.S. Patent 3,282,875 and
can be made by copolymerization of tetrafluoroethylene (TFE) and the
perfluorinated vinyl ether CF₂=CF-O-CF₂CF(CF₃)-O-CF₂CF₂SO₂F,
perfluoro(3,6-dioxo-4-methyl-7-octenesulfonyl fluoride) (PDMOF), followed by
conversion to sulfonate groups by hydrolysis of the sulfonyl halide groups and ion
exchanging to convert to the desired hydrogen ion form. One preferred polymer
of the type disclosed in U.S. Patents 4,358,545 and 4,940,525 has the side chain
-O-CF₂CF₂SO₃X, wherein X is as defined above. This polymer can be made by
copolymerization of tetrafluoroethylene (TFE) and the perfluorinated vinyl ether
CF₂=CF-O-CF₂CF₂SO₂F, perfluoro(3-oxa-4-pentenesulfonyl fluoride) (POPF),
followed by hydrolysis and acid exchange. Perfluorosulfonic acid polymers of the
types described in this paragraph are sold under the trademark Nafion® by E.I. du
Pont de Nemours, & Co., Inc. of Wilmington, Delaware, USA.

The ratio of the monomers with the ion exchange groups to other
monomers that make up the polymer determines the acidity of the polymer, that is
the equivalents of base, such as sodium hydroxide, that will be neutralized by one
gram of polymer. It is convenient to describe and compare the polymers in terms
of their "ion exchange ratio" or "IXR". This is defined as the number of carbon
atoms in the polymer backbone in relation to the number of cation exchange
groups. A wide range of IXR values for the polymer is possible. Typically,
however, the IXR range used is from about 7 to about 33. For perfluorinated
polymers of the type described above, the cation exchange capacity of a polymer
is often expressed in terms of equivalent weight (EW). For the purposes of this
application, equivalent weight (EW) is defined to be the weight of the polymer in
acid form required to neutralize one equivalent of NaOH. In the case of a

sulfonate polymer where the polymer comprises a perfluorocarbon backbone and the side chain is $-O-CF_2-CF(CF_3)-O-CF_2-CF_2-SO_3H$, the equivalent weight range which corresponds to an IXR of about 7 to about 33 is about 700 EW to about 2000 EW. IXR for this polymer can be related to equivalent weight using the following formula: $50 \text{ IXR} + 344 = \text{EW}$. While generally the same IXR range is used for sulfonate polymers disclosed in U.S. Patents 4,358,545 and 4,940,525, the equivalent weight is somewhat lower because of the lower molecular weight of the monomer unit containing a cation exchange group. For the IXR range of about 7 to about 33, the corresponding equivalent weight range is about 500 EW to about 1800 EW. IXR for this polymer can be related to equivalent weight using the following formula: $50 \text{ IXR} + 178 = \text{EW}$.

IXR is used in this application to describe either hydrolyzed polymer which contains ion exchange groups or unhydrolyzed polymer (also referred to as "precursor" or "precursor polymer") that contains precursor groups which will subsequently be converted to the acidic form during the manufacture of the catalyst.

As illustrated in Figures 1-4 for two preferred catalysts in accordance with the invention, the catalyst has a very open structure which provides a high surface area. In the catalyst of the invention, the surface area is about $0.01 \text{ m}^2/\text{g}$ to about $5 \text{ m}^2/\text{g}$, preferably $0.1 \text{ m}^2/\text{g}$ to $5 \text{ m}^2/\text{g}$. Depending on the process conditions used in its manufacture, the surface area can be adjusted as desirable for a particular end use. As may be seen in the structure of the catalyst shown in Figures 1 and 2, the structure may have a more leaf-like structure which, in the catalyst depicted, provides a surface area of $0.01\text{-}0.05 \text{ m}^2/\text{g}$. The structure of the catalyst has more of an open cell foam appearance in the embodiment depicted in Figures 3 and 4 which provides a surface area of $1\text{-}5 \text{ m}^2/\text{g}$. Surface areas are measured using the BET method.

In addition, the catalyst is preferably substantially free of pores having a size of about 1.7 to about 300 nm as measured by the BET absorption method. When the BET procedure is run on samples of this form of the catalyst, the results indicate that there are essentially no pores in this size range. This form of the catalyst of the invention is especially useful for processes involving reactions

forming oligomers or for feedstocks containing materials which can clog small pores.

Preferably, the solid acid catalyst has a bulk density of about 0.1 to 0.9 g/cc.

- 5 Preferred solid acid catalysts in accordance with the invention have a resiliency factor of 80%. Resiliency factor a measure of how well the catalyst recovers after being subjected to pressing or other mechanical distortions of its structure. These preferred catalysts are able to withstand rough handling during manufacture, use and regeneration. The catalysts are also dimensionally stable.
- 10 By dimensionally stable is meant that the catalysts do not change in any dimension by greater to 10% when heated to 100°C and cooled.

- In the process for making a solid acid catalyst in accordance with the invention, highly fluorinated acidic polymer or precursor thereof is exposed to a pressurized fluid to produce fluid-swelled polymer or polymer precursor. Any of
- 15 a wide variety of such fluids can be used provided that they are capable of swelling the polymer of the precursor. Under the pressures used, the fluid may be in the form of a liquid, a gas or a supercritical fluid. Any suitable vessel may be used which can withstand the pressures employed. Such vessels should be acid resistant when the polymer is in the acid form since it is corrosive. The pressure
- 20 used should to swell the polymer with sufficient fluid so that it expands as desired in the later steps of the process.

- For perfluorinated sulfonic acid polymer, the polymer is advantageously employed in either acid or sulfonyl halide precursor form. When sulfonyl halide, e.g., sulfonyl fluoride, the fluid is preferably selected from the
- 25 group consisting of SO₂ and CO₂. For sulfonic acid polymer, the fluid is preferably selected from the group consisting of SO₂ and CO₂, with the fluid further comprising water.

- In the process of the invention, the fluid-swelled polymer or polymer precursor is heated to a temperature above the softening point of said fluid-swelled polymer or precursor. For perfluorinated sulfonyl fluoride polymer, this
- 30 temperature is typically in the range of 150-300°C and the temperature used in the process is somewhat lower due to softening point depression caused by the

swelling fluid. Perfluorinated sulfonic acid polymer has a somewhat higher softening point range and its softening point will be similarly affected. The pressure of the pressurizing fluid is then reduced sufficiently quickly that gases escape from said fluid-swelled polymer and the escaping gases expand said polymer or polymer precursor into a porous structure. If the fluid is a liquid or a supercritical fluid, a phase change will occur to provide the gases to expand the polymer.

The polymer or polymer precursor is cooled to at least partially retain the porous structure. It is preferable in the process for the cooling of the polymer or polymer precursor to at least partially retain the porous structure to be caused by said reduction in pressure. Consequently, it is advantageous for the fluid swelled polymer, at the time of pressure release, to be only slightly above the softening point of the swelled polymer so that the structure imparted by the escaping gases will be quickly "frozen" by the temperature drop caused by the expanding gases.

Typically, the processes yield a mass of porous polymer which can be cut or broken into particles of the desired size. Alternatively, the porous polymer may be formed into a mold which impart a shape adapted for a particular end use.

When used in particulate form, the size of the catalyst particles can be adjusted to suit the equipment or process in which the catalyst is employed. Preferably, catalyst is in a form having an average particle size of at least about 0.5 mm, most preferably, at least about 1.0 mm. Since the porous polymer provides high surface area, the particles can be large, i.e., up to 50 mm, if desired. The porous highly fluorinated polymer of the invention combines the virtues of high surface area with the easy handling, including filling, charging, filtering, and cleaning, of large particle catalysts.

Another particular advantage of the highly fluorinated, and more especially the perfluorinated acidic organic polymers, is that they resist fouling because of their low surface energy. However, if fouled, they may be easily cleaned. Accumulation of organic material on the surface of the polymer catalyst can interfere with contact of the acidic organic polymer catalyst with the material being treated with the catalyst, and thereby slow reaction, and perhaps render it

less complete. Also, should metal ion salts be present in the feedstock, they may reduce the activity of the acidic organic polymer catalyst. Because of their great chemical stability, the perfluorosulfonic acid acidic organic polymers may be cleaned by a wide variety of means consistent with the nature of the contamination. Those skilled in the art will be familiar with the various techniques, which include, steam cleaning, exposure to oxidizing agents such as chlorine, aqueous solutions of sodium or calcium hypochlorite, or hot nitric acid. Steaming has been found to be a preferred non-chemical method of cleaning the acidic organic polymers. For the removal of metal ion contamination, exposure to aqueous inorganic acids, preferably hydrochloric acid or nitric acid in the range of 1-10%, is desirable.

The catalysts made in accordance with this invention exhibit high activity and long life in a variety of reactions, including but not limited to, esterifications, alkylations, acylations, dimerizations, polymerizations, isomerizations, and conversion of organic sulfur compounds that are insoluble in aqueous or alkaline media to forms that are soluble in said media.

TEST METHODS

Test are run on catalyst in the hydrolyzed form.

BET Surface Area & Nitrogen Porosimetry: SA & N2-PVD

The surface areas of powders and solids are calculated using the adsorption of nitrogen at its boiling point via the BET method [S. Brunauer, P. Emmett, and E. Teller, J. Amer. Chem. Soc. 60, 309 (1938)]. Micromeritics ASAP 2400 adsorption units are used to measure the amount of nitrogen sorbed; the BET equation is used to calculate the amount of nitrogen corresponding to a monolayer for a given sample. Using an area of 16.2 sq. Angstroms (0.162 nm²) per nitrogen molecule, the surface area per gram of solid is calculated. Surface area standards (from the National Institute of Standards & Technology) are run periodically to insure that the reported values are accurate to within a few percent for samples with areas > 5 m²/g. The BET equation may be written in linear form:

$$P/P_0 / V \cdot (1 - P/P_0) = 1/c \cdot V_m + (c-1) \cdot P/P_0 / c \cdot V_m$$

- where the volume of nitrogen adsorbed, V , in cc STP/g, is measured as a function of relative pressure, P/P_0 , where P is the measured pressure and P_0 is the pressure of condensing nitrogen at the temperature of the experiment, typically 77°K. V_m is the volume of an adsorbed monolayer and the constant c is related to the average heat of adsorption on the surface (hence, sometimes called a “surface energy” term). Both V_m and c are found experimentally by fitting the linear portion of the adsorption isotherm, generally in the P/P_0 regime < 0.3 . Values of c vary significantly from material to material and, unless precautions are taken, there are sufficient variations in states of dehydration, surface chemistry, etc., so that the c values cannot readily be interpreted.

Pore size distributions:

Pore sizes are calculated using the BJH method [Barret, Joyner, and Halenda, J. Amer. Chem. Soc. 73, 373 (1951)].

There are two important features of the BJH method:

- cumulative pore volume (17-3000 Å (1.7-300 nm)); record this value
- calculated pore volumes vs. pore diameters (pore distribution)

A cumulative volume > 0.05 cc/g shows the presence of pores; the higher the value, the greater the contribution to the surface area to the calculated Cumulative Surface Area.

20 Resiliency Factor

- Resiliency Factor is measured slicing the catalyst sample into 0.5 inch (13 mm) (original thickness) thick pieces. One of the pieces is placed between two sheets of aluminum foil and pressed two times in a hydraulic press to a thickness of 5 to 10 mils (125 to 250 μm). The sample is removed from the press and, after two hours at room temperature, the thickness, defined here as the recovered thickness, is measured. Resiliency Factor is the recovered thickness divided by the original thickness and is expressed as a percentage.

Densities of products isolated from vessels:

- Samples were cut from the products recovered from the pressure vessel. Their volumes were calculated and weights determined.

Sample A was prepared as in Example 3 using 50 g perfluorinated sulfonyl fluoride (EW 1080) and 150 g CO₂ at 260°C. The vessel was cooled to 240°C before being vented. The product density was 0.48 g/ml.

- Sample B was prepared like Sample A except the process was carried out
5 at 250°C and vented at 250°C. Its density was 0.14 g/ml.

Example 1

Preparation of Porous Sulfonyl Fluoride Precursor Polymer from Sulfur Dioxide and Hydrolysis to the Sulfonic Acid Form

- A Hastelloy® shaker tube was charged with 50 g perfluorinated sulfonyl
10 fluoride polymer of the type described in U.S. Patent 3,282,875 (DXR= 14, EW= 1050) and 150 g sulfur dioxide. After heating and shaking at 250°C for 3 hours at 2000 psi (14 mPa), the vessel was cooled to 245°C and vented. Because the vessel was completely filled with a soft porous plug, it is concluded that the perfluorinated sulfonyl fluoride polymer was completely dissolved in the sulfur
15 dioxide. When the pressure was released, the solution foamed and filled the vessel as the sulfur dioxide escaped.

The large cells of the porous polymer were all open but there were some closed small cells on the walls that prevented the porous polymer from sinking in acetone.

- 20 The cylindrical product was sliced into 0.5 inch (13 mm) thick disks, then pressed two times between aluminum foil in a hydraulic press. At first, the disks were thin circles, but in 2 hours they recovered to the original 0.2 inch (13 mm) thickness. The disks were hydrolyzed in a solution consisting of 56% water, 30% dimethylsulfoxide, and 14% potassium hydroxide. The solution was forced into
25 the spongy porous polymer by pressing it and allowing it to expand while under the surface of the solution. After heating on a steam bath for two hours, the solution and spongy porous polymer were stored at room temperature for two days. The disks had expanded and were stiff. Treatment with 600 ml 10:90 concentrated nitric acid:water solution, using the squeezing procedure to
30 thoroughly distribute the acid throughout the structure, converted the porous polymer to the hydrogen ion or acid form. After four days, the product was repeatedly washed with deionized water, using the squeezing technique until the

water was pH 6. The product was dried at room temperature for at least two days prior to testing for catalytic activity. Bulk density 0.14 g/ml.

Example 2

Preparation of Porous Sulfonyl Fluoride Precursor Polymer from Carbon

Dioxide

5 The reaction of Example 1 was repeated using 50 g perfluorinated sulfonyl fluoride polymer of the type described in U.S. Patent 3,282,875 (IXR= 13, EW=990) with 150 g carbon dioxide at 250°C for 3 hours. A soft, small pore product equivalent to about one quarter of the vessel's volume resulted having a
10 surface area of 4.4 m²/g. Bulk density 0.18 g/ml.

Example 3

Preparation of Porous Nafion® Sulfonic Acid Using Sulfur Dioxide and

Water

A shaker tube made of Hastelloy®S C was charged with 54 g (0.05 mol)
15 perfluorinated sulfonic acid polymer (IXR= 16, EW 1080) and 3.6 g (0.2 moles) water. The vessel was charged with 150 g sulfur dioxide followed by heating and shaking at 250°C under 2400 psi (156.6 MPa) for 3 hours. The gases were vented rapidly. The polymer was recovered as a porous strip. A section from the inside of the product sank slowly in acetone, demonstrating that it had an open structure.
20 It had a gray color that was removed by soaking in 30% aqueous nitric acid. Bulk density 0.22.

Examples 4-12

Porous Perfluorinated Sulfonic Acid Preparations Using Carbon Dioxide

As summarized in the following Table 1, a variety of porous perfluorinated
25 sulfonic acid compositions were prepared. All used pellets of the polymer in a shaker tube. After agitation for three hours, the vessels were rapidly vented and cooled to give porous strips of polymer. Some were covered with a thin layer of polymer film over an interior porous structure. As the ratio of water to carbon dioxide was increased, the pore size became smaller. Small strips of the products
30 sank in acetone, indicating an open cell structure.

Table I
Preparation of Porous Perfluorinated Sulfonic Acid

<u>Example</u>	<u>EW</u>	<u>Nafion®</u>	<u>Water</u> <u>g</u>	<u>Temp</u> <u>°C</u>	<u>Time</u> <u>hrs</u>	<u>Pressure</u> <u>psi (MPa)</u>
		<u>Sulfonic</u> <u>Acid</u> <u>g</u>				
4	1080	54	3.6	250	3	5400 (37.2)
5	1080	27	1.8	250	3	5000 (34.5)
6	1080	54	3.6	240	3	5100 (35.2)
7	1080	81	5.4	240	3	5500 (37.9)
8	1080	108	7.2	250	3	6200 (42.7)
9	1080	54	9	250	3	5500 (37.9)
10	1080	54	18	250	3	5000+ (34.5+)
11	1080	54	36	250	3	5900 (40.7)
12	915	55	4.4	250	3	5800 (40.0)

- The porous products were chopped to small pieces in a Wiley mill with the resin at room temperature and treated with 10-15% aqueous nitric acid to remove the metal contaminants sometimes contributed by the metal vessel. The final porous granules were tested as catalysts for alkylation, olefin rearrangement, and acylation reactions as described in the following examples.

Conditions for Examples 13-18

- Catalyst testing was carried out in the liquid phase with a glass batch reactor. The porous catalyst of this invention was that made in Example 10. "NR50" refers to Nafion® Superaacid Catalyst NR50, available from the DuPont Company, Wilmington Delaware, USA. Prior to testing, the Nafion® resins were dried for more than 4 hours in a vacuum oven at 150°C. In the batch reactor, liquid samples were taken at certain time intervals and analyzed with GC. Occasionally, GC/MS and NMR were used for product analysis as well. Reaction rates are stated as millimoles of product formed per gram of catalyst per hour (mmole-gram-catalyst⁻¹·hr⁻¹).

Example 13**Porous Perfluorinated Sulfonic Acid Catalysis of Olefin Isomerization**

1-Dodecene isomerization: 1-Dodecene isomerization to its linear isomers was carried out in the liquid phase at 75°C. For a typical test, 10 g of 1-dodecene which was fresh distilled, 30 g of decane and 1 g of solid acid catalyst which was predried were charged into a two-neck flash with a magnetic stir bar for mixing. Decane serves as solvent and internal standard for the GC analysis. Liquid samples were taken at certain time intervals and analyzed by GC. Very good material balances (>98%) were obtained and formation of oligomers was negligible under these conditions.

Example 14**Rate of isomerization of 1-dodecene to the internal olefins at 80°C**

1-Dodecene isomerization rates were calculated from the data obtained at low 1-dodecene conversions (<30%) at conditions similar to those of the preceding example. Table 2 summarizes the results.

Table 2

Catalyst	Rate (mmole-gram-catalyst ⁻¹ -hr ⁻¹)
NR50	3.8
Porous Catalyst	23.7

Example 15**Porous Perfluorinated Sulfonic Acid Catalysis of Alkylation**

p-Xylene alkylation with 1-dodecene was carried out at 80°C. The reaction mixture contained 10 g 1-dodecene, 21.9 g p-xylene and 1 g solid acid catalyst. The isomerization of the 1-dodecene to the internal olefins during the reaction leads to the formation of five alkylation products (2-, 3-, 4-, 5-, and 6-dodecyl-p-xylene).

Example 16**Rates and Yields in Porous Perfluorinated Sulfonic Acid Catalyzed Alkylation**

Reaction rates and product yields after 60 min. for the alkylation of p-xylene with 1-dodecene at 80°C (p-xylene/1-dodecene/ perfluorosulfonic acid polymer pellets (3 mm - 4 mm in size) = 29.3/10.0/1.0 g) are summarized in Table 3.

Table 3

<u>Catalyst</u>	<u>Rate (mmole-gram-catalyst⁻¹·hr⁻¹)</u>	<u>Yield (%)</u>
NR50	1	1.7
Porous Catalyst	24.6	33.8

Example 17**Porous Perfluorinated Sulfonic Acid Catalysis of an Acylation Reaction**

Acylation of m-xylene with benzoyl chloride was carried out at 140°C

- 5 with 2 g catalyst, 14 g benzoyl chloride and 21.2 g m-xylene. The products are dimethylbenzophenones.

Example 18**Rates and Yields in Porous Perfluorinated Sulfonic Acid Catalyzed Acylation**

Reaction rates and product yields after 30 min. for acylation of m-xylene

- 10 with benzoyl chloride at 140°C (m-xylene/benzoyl chloride/perfluorosulfonic acid polymer pellets (3 mm - 4 mm in size) = 21.0/14.0/1.0 g) are summarized in Table 4.

Table 4

<u>Catalyst</u>	<u>Rate (mmole-gram-catalyst⁻¹·hr⁻¹)</u>	<u>Yield (%)</u>
NR50	68	32
Porous Catalyst	510	92.8

Example 19**Preparation of Porous Sulfonic Acid Catalyst**

- 15 The product was prepared as in Example 1 using 60 g perfluorinated sulfonyl fluoride polymer, and 150 g sulfur dioxide. The conditions were 250°C for 3 hours, cooled to 200°C, then the sulfur dioxide was vented. The plug of polymer was pressed to break any closed cells, cut into small chunks, and fed into
- 20 a Wiley mill at room temperature. The ground product was converted to the free acid by treatment with 30% dimethylsulfoxide, 14% potassium hydroxide, and 56% water for 3 days at room temperature followed by 2 hours of heating in a hot water bath. The product was washed with water and converted to the free acid with 15% HNO₃. Weight after air drying is 57 g. Bulk density was measured to
- 25 be approximately 0.35.

WHAT IS CLAIMED IS:

1. A solid acid catalyst comprising porous highly fluorinated acidic polymer, said catalyst comprising at least about 90 wt.% highly fluorinated acidic polymer and having a surface area of about $0.01 \text{ m}^2/\text{g}$ to about $5 \text{ m}^2/\text{g}$
- 5 2. The solid acid catalyst of claim 1 having a bulk density of about 0.1 to 0.9 g/cc .
3. The solid acid catalyst of claim 1 wherein the catalyst is substantially free of pores having a size of about 1.7 to about 300 nm as measured by the BET absorption method.
- 10 4. The solid acid catalyst of claim 1 comprising at least about 95 wt. \% highly fluorinated acidic polymer.
5. The solid acid catalyst of claim 1 having a resiliency factor of 80% .
6. The solid acid catalyst of claim 1 wherein said catalyst is
- 15 dimensionally stable.
7. The solid acid catalyst of claim 1 wherein said highly fluorinated acidic polymer comprises highly fluorinated sulfonic acid polymer.
8. A process for making a solid acid catalyst comprising:
exposing highly fluorinated acidic polymer or precursor thereof to a
- 20 pressurized fluid to produce fluid-swelled polymer or polymer precursor;
heating said fluid-swelled polymer or polymer precursor to a temperature above the softening point of said fluid-swelled polymer or precursor;
reducing the pressure of said pressurizing fluid sufficiently quickly that gases escape from said fluid-swelled polymer, said escaping gases expanding
- 25 said polymer or polymer precursor into a porous structure; and
cooling said polymer or polymer precursor to at least partially retain said porous structure.
9. The process of claim 8 wherein said polymer is high fluorinated sulfonyl halide polymer and said fluid is selected from the group consisting of
- 30 SO_2 and CO_2 .

10. The process of claim 8 wherein said polymer is highly fluorinated sulfonic acid polymer and said fluid is selected from the group consisting of SO₂ and CO₂, said fluid further comprising water.

11. The process of claim 8 wherein said cooling of said polymer or
5 polymer precursor to at least partially retain said porous structure is cooling caused by said reduction in pressure.

1/2

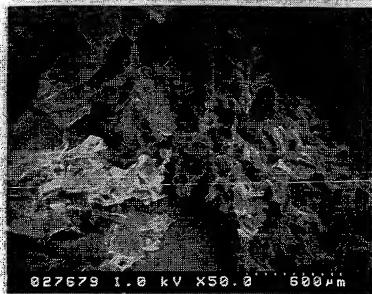


FIG. 1



FIG. 2

2/2

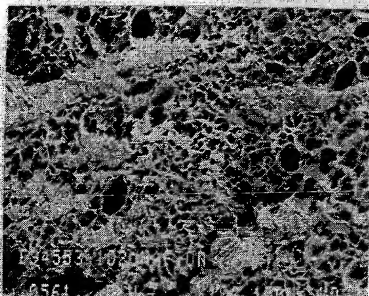


FIG. 3

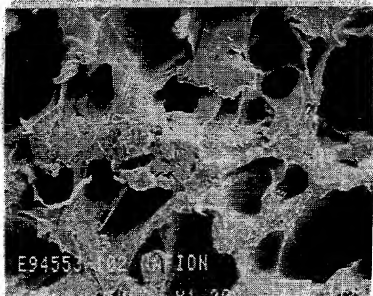


FIG. 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/02102

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B01J31/08 C08J9/18 C08L27/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B01J C08J C08F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 94 28059 A (DU PONT) 8 December 1994 (1994-12-08) the whole document	1,4,6, 8-11
A	US 5 430 212 A (BUTT MARTIN H D ET AL) 4 July 1995 (1995-07-04) cited in the application	1,3,6,7
A	WO 96 19288 A (DU PONT) 27 June 1996 (1996-06-27)	1,2,4,6
A	US 4 180 695 A (MCCLURE JAMES D) 25 December 1979 (1979-12-25)	

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"I" document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (see specification)

"O" document relating to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"A" document member of the same patent family

Date of the actual completion of the international search

6 June 2000

Date of mailing of the international search report

15/06/2000

Name and mailing address of the ISA
European Patent Office, P.B. 5616 Petersilien 2
NL - 2280 HV Rijswijk
Tel: (+31-70) 340-2040, Tx: 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Zuurdeeg, B

INTERNATIONAL SEARCH REPORT

information on patent family members

Inter-
national Application No
PCT/US 00/02102

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9428059 A	08-12-1994	AU 4541393 A	24-01-1994
		AU 6531994 A	20-12-1994
		CA 2138250 A	06-01-1994
		CN 1088152 A	22-06-1994
		EP 0647250 A	12-04-1995
		JP 7508548 T	21-09-1995
		WO 9400511 A	06-01-1994
		US 5939198 A	17-08-1999
		US 5721283 A	24-02-1998
		US 5840775 A	24-11-1998
US 5430212 A	04-07-1995	US 5315033 A	24-05-1994
		US 5233102 A	03-08-1993
		US 5094995 A	10-03-1992
WO 9619288 A	27-06-1996	US 5824622 A	20-10-1998
		CN 1170373 A	14-01-1998
		DE 69504535 D	08-10-1998
		DE 69504535 T	01-04-1999
		DE 69512204 D	21-10-1999
		DE 69512204 T	11-05-2000
		EP 0739239 A	30-10-1996
		EP 0799091 A	08-10-1997
		ES 2139187 T	01-02-2000
		JP 9508057 T	19-08-1997
		JP 10511648 T	10-11-1998
		WO 9519222 A	20-07-1995
		US 5948946 A	07-09-1999
		US 6034290 A	07-03-2000
		US 5916837 A	29-06-1999
US 4180695 A	25-12-1979	US 4022847 A	10-05-1977
		US 4041090 A	09-08-1977
		US 4052474 A	04-10-1977